

# Prospects for CP violation at the Tevatron (all angles)

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Petar Maksimovic, for CDF and D0

CDF and D0 caught between

- 1) **idealistic projections** from long ago
- 2) **realistic extrapolations** from recent measurements

⇒ report on (2) only in several cases  
show progress in other areas

# Hadronic environment

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## Disadvantages:

- "messy"
- opp. side b-hadron not reconstructed 20-40%  
of time (coverage an issue -- points for D0)

## Advantages:

- huge  $b\bar{b}$  cross-section ( $\sim 100 \mu\text{b}$  total)
- (still only 1 per  $\sim 1000$  soft QCD collisions)

$\Rightarrow$  live and die by the trigger

(displaced track triggers: CDF from beginning,  
D0 commissioning now; faster DAQ -- points for CDF)

# Ingredient #1: Luminosity

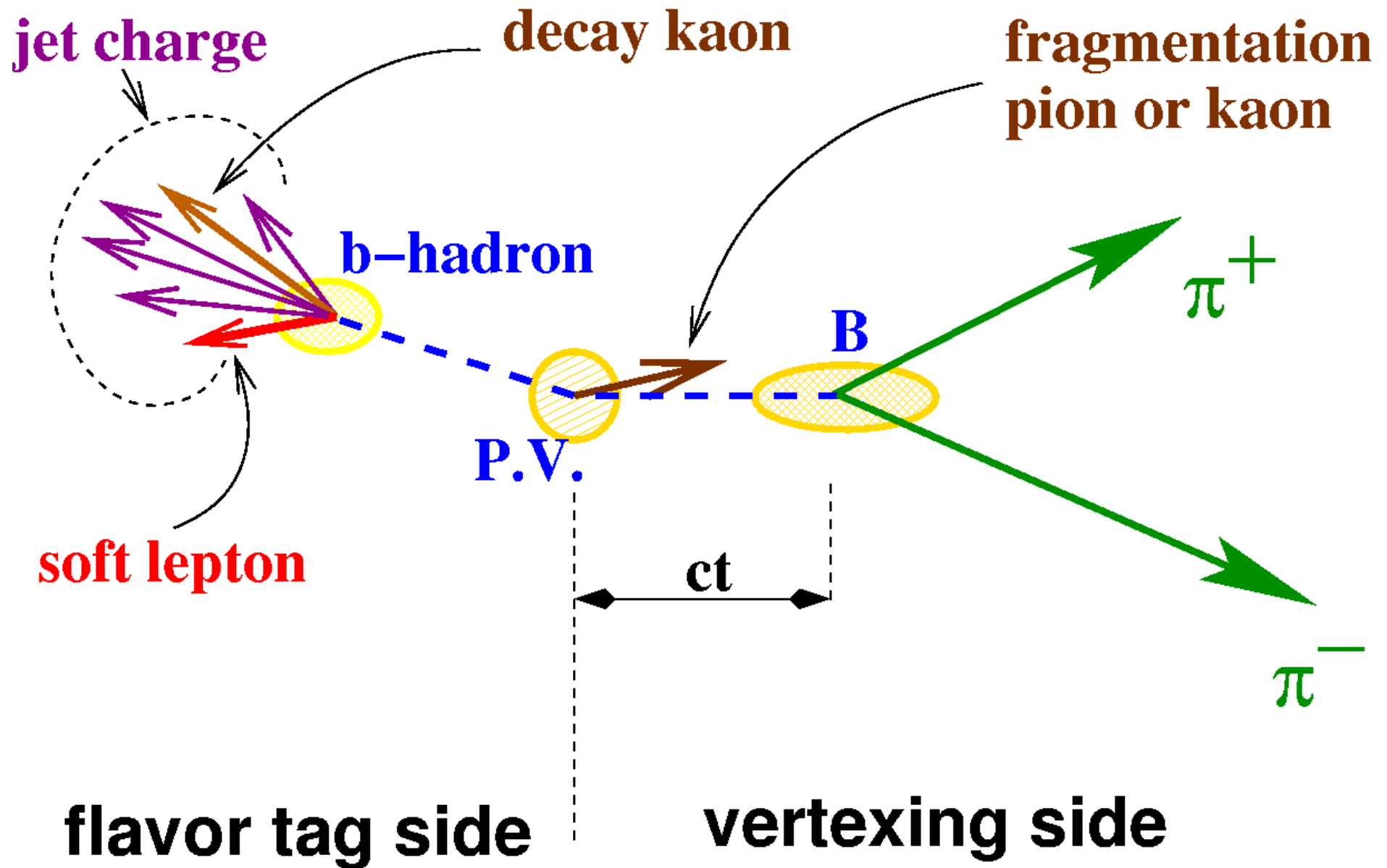
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Luminosity in inverse fb	By 2008	By 2010 + recycler
Base projection	2.11	4.41
Design projection	3.78	8.57

(more optimistic, relies on electron cooling)

- Consider **2 inv.fb** and **3.5 inv.fb**
- Not clear if current B triggers are OK > 2007

# Ingredient #2: flavor tagging



# Ingredient #2: flavor tagging

$\epsilon D^2$ [%]	CDF	D0
Soft Muons	$0.66 \pm 0.09$	$1.6 \pm 1.1$
Soft Electrons	?	?
Jet Charge	?	$3.3 \pm 1.7$
Same Side	$1.9 \pm 0.9$	$5.5 \pm 2.0$
Opp.Side Kaon	? [2.4]	N/A
Same Side Kaon	? [4.2]	N/A

- For projections, CDF is using  $\epsilon D^2 = 5\%$   
(Down from  $> 10\%$  since Kaon tagging not ready)

## Ingredient #3: time resolution

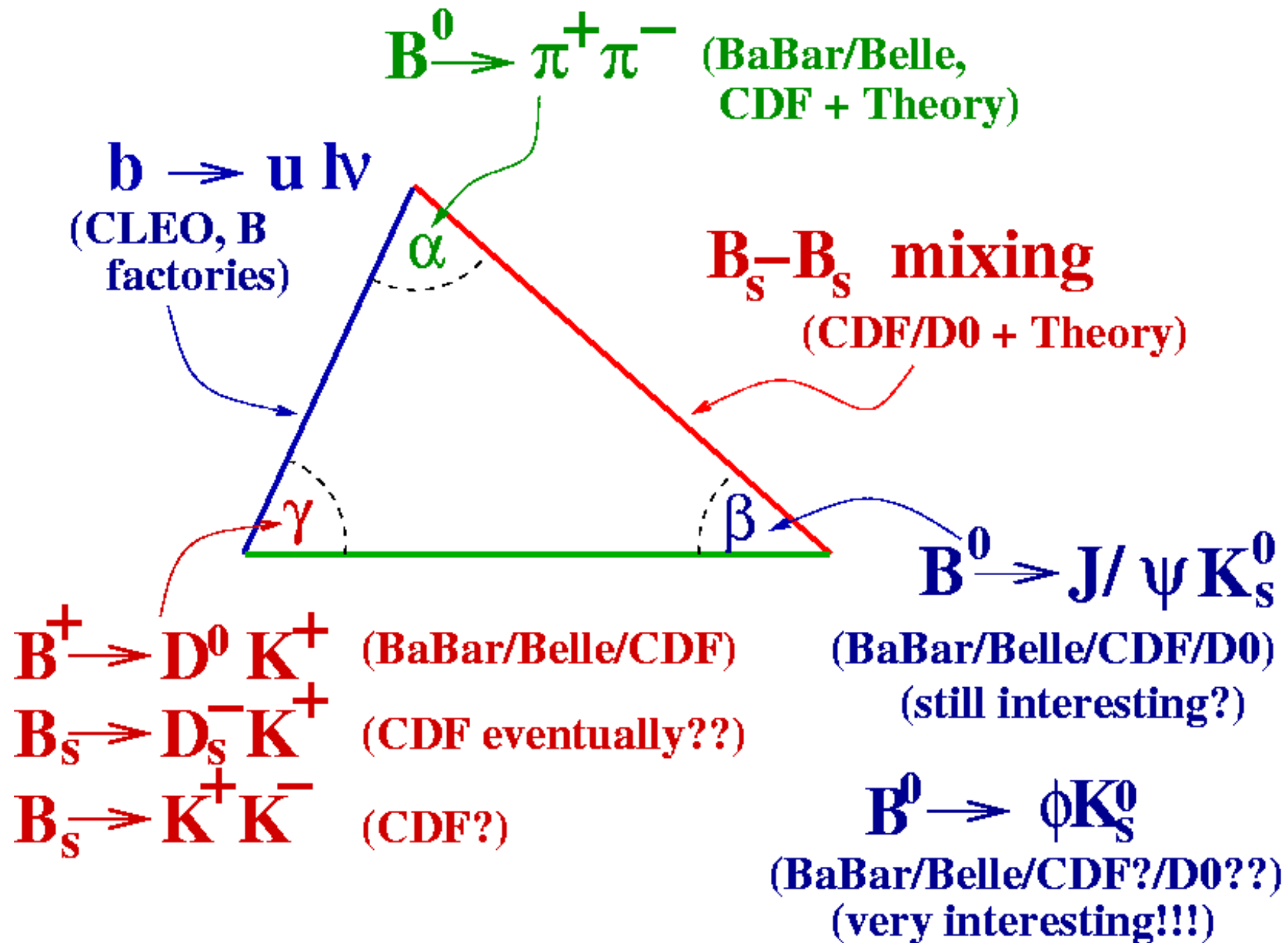
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	Proper time resol [fs]
CDF	67 (50 with L00)
D0	110

## Other expected improvements:

- D0: **significant** trigger upgrade just installed -- **adding track-based triggers!**
- CDF: upgrades to DAQ and trigger logic in 2004 and 2005
- CDF's Layer 00 ready for physics

# Overall game plan



# Composition of $B \rightarrow h^+ h^-$

- Mixture of:

$$B_d \rightarrow K\pi$$

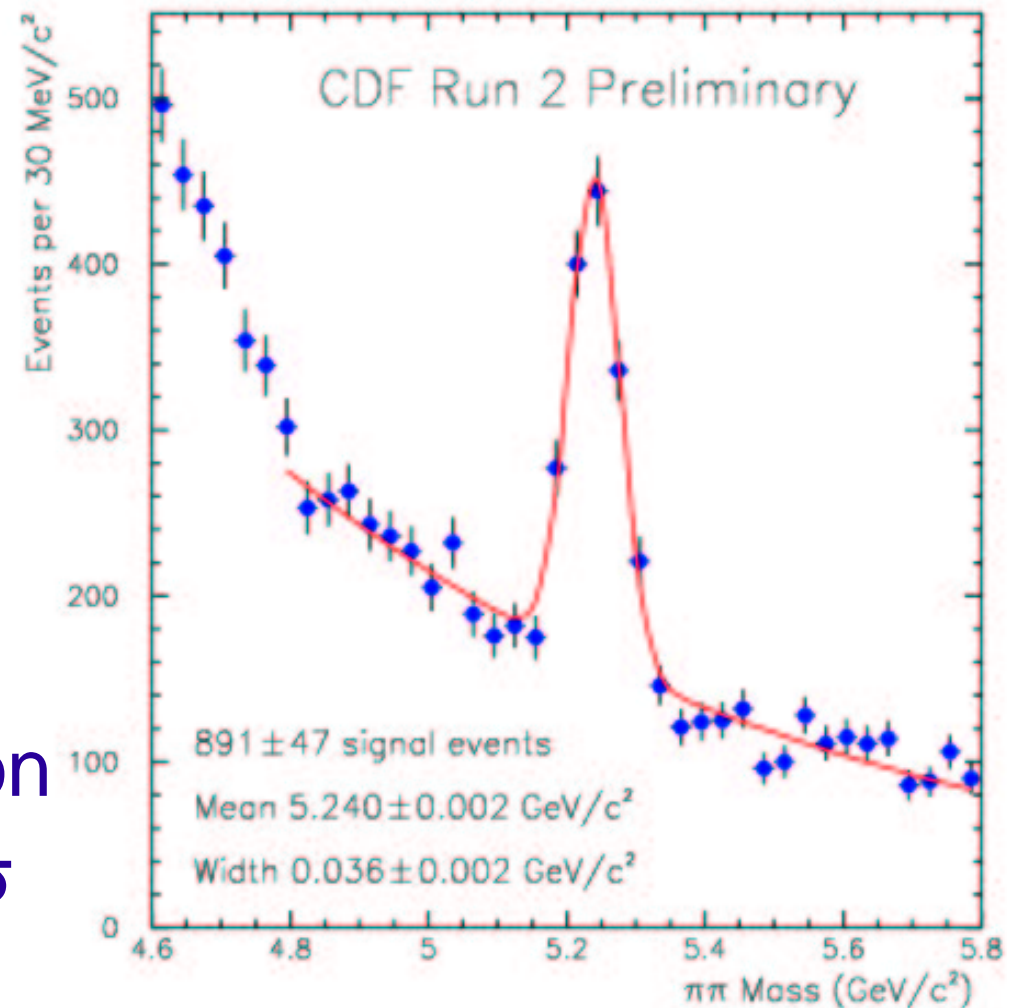
$$B_d \rightarrow \pi\pi$$

$$B_s \rightarrow KK$$

$$B_s \rightarrow K\pi$$

- Can't use ToF
- Effective  $K/\pi$  separation of  $dE/dx$  only  $\sim 1.16 \sigma$

( $\pi^+\pi^-$  hypothesis)



⇒ Separate on statistical basis

# Multi-dim unbinned likelihood fit

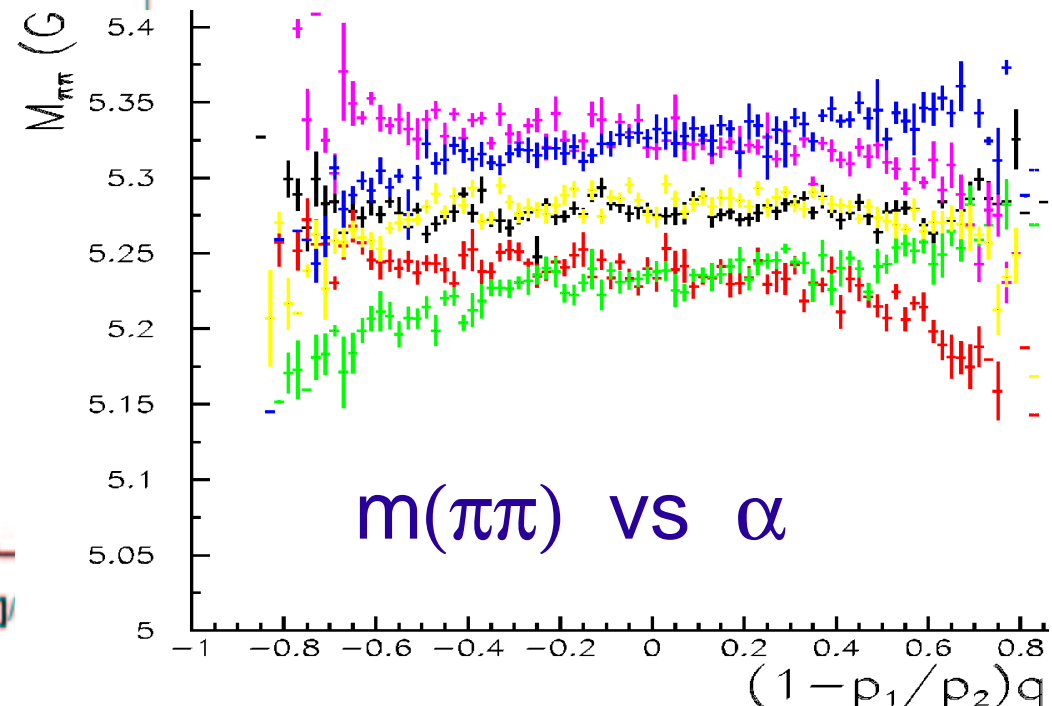
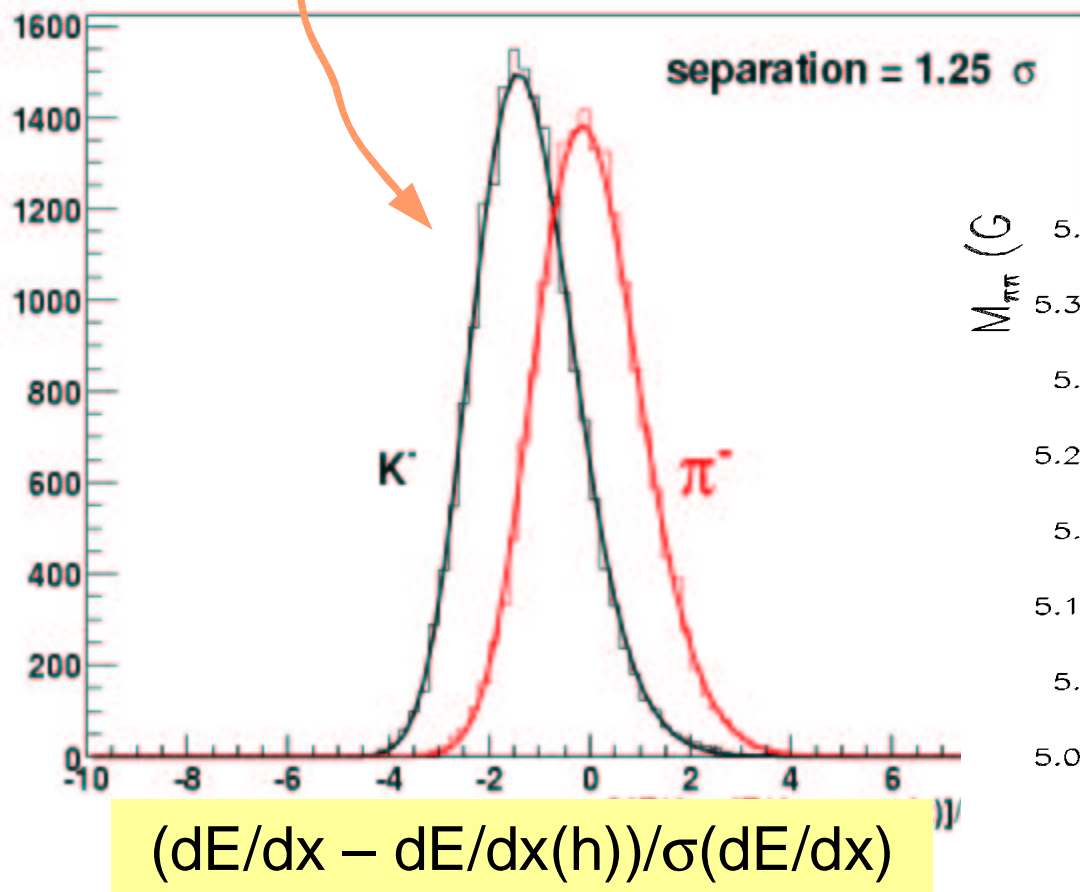
For each particle, use:

- $dE/dx$  (calibrated on  $D^*$ )
- Kinematic:  $m(\pi\pi)$  and  $\alpha$

Pion momenta,  $p_1 < p_2$

$$\alpha = \left( 1 - \frac{p_1}{p_2} \right) \cdot q_1$$

Charge of #1



# $B \rightarrow h^+ h^-$ Results

- 65/pb of data
- First observation of
- Includes error on  $f_s/f_d$

mode	Yield (65 pb <sup>-1</sup> )
$B^0 \rightarrow K\pi$	$148 \pm 17(\text{stat.}) \pm 17(\text{syst})$
$B^0 \rightarrow \pi\pi$	$39 \pm 14(\text{stat.}) \pm 17(\text{syst})$
$B_s \rightarrow KK$	$90 \pm 17(\text{stat.}) \pm 17(\text{syst})$
$B_s \rightarrow K\pi$	$3 \pm 11(\text{stat.}) \pm 17(\text{syst})$

$$\frac{BR(B_s \rightarrow K^\pm K^\mp)}{BR(B_d \rightarrow K^\pm \pi^\mp)} = 2.71 \pm 1.15$$

Already interesting

- Direct  $A_{CP} \sim 0$ , syst comparable to B factories

$$A_{CP}(B^0 \rightarrow K^- \pi^+) = 0.02 \pm 0.15 (\text{stat}) \pm 0.02 (\text{syst})$$

# Projected yields in $B \rightarrow h^+ h^-$

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Mode	Yield $2 \text{ fb}^{-1}$	Yield $3.5 \text{ fb}^{-1}$
$B_d \rightarrow K\pi$	6700	11,725
$B_d \rightarrow \pi\pi$	1770	3097
$B_s \rightarrow KK$	4040	7070
$B_s \rightarrow K\pi$	1070	1870

- $B_s \rightarrow K^+ \pi^-$  -- **from theory** (no sensitivity yet)
- Simultaneous fit to kinematics + mass + dE/dx  
 $\Rightarrow$  errors not  $\sim \sqrt{N}$  -- **N must be scaled by x0.6**
- Systematics dominated by dE/dx  
calibrated by  $D^*$   $\Rightarrow$  **improve with more data**

# Angles $\alpha$ and $\gamma$ : fitting for $A_{CP}$

- Use flavor tagging --  $\epsilon D^2 = 5\%$
- *R.Fleischer, PLB 459 (1999) 306*
- Separate  $A_{CP}$  components into  $B^0 \rightarrow \pi^+\pi^-$  (measures  $\sin 2\alpha$ ) and  $B_s \rightarrow K^+K^-$  ( $\sin 2\gamma$ )

$$A_{CP}(B^0) = A_{CP}^{\text{dir}} \cos \Delta m_d t + A_{CP}^{\text{mix}} \sin \Delta m_d t$$

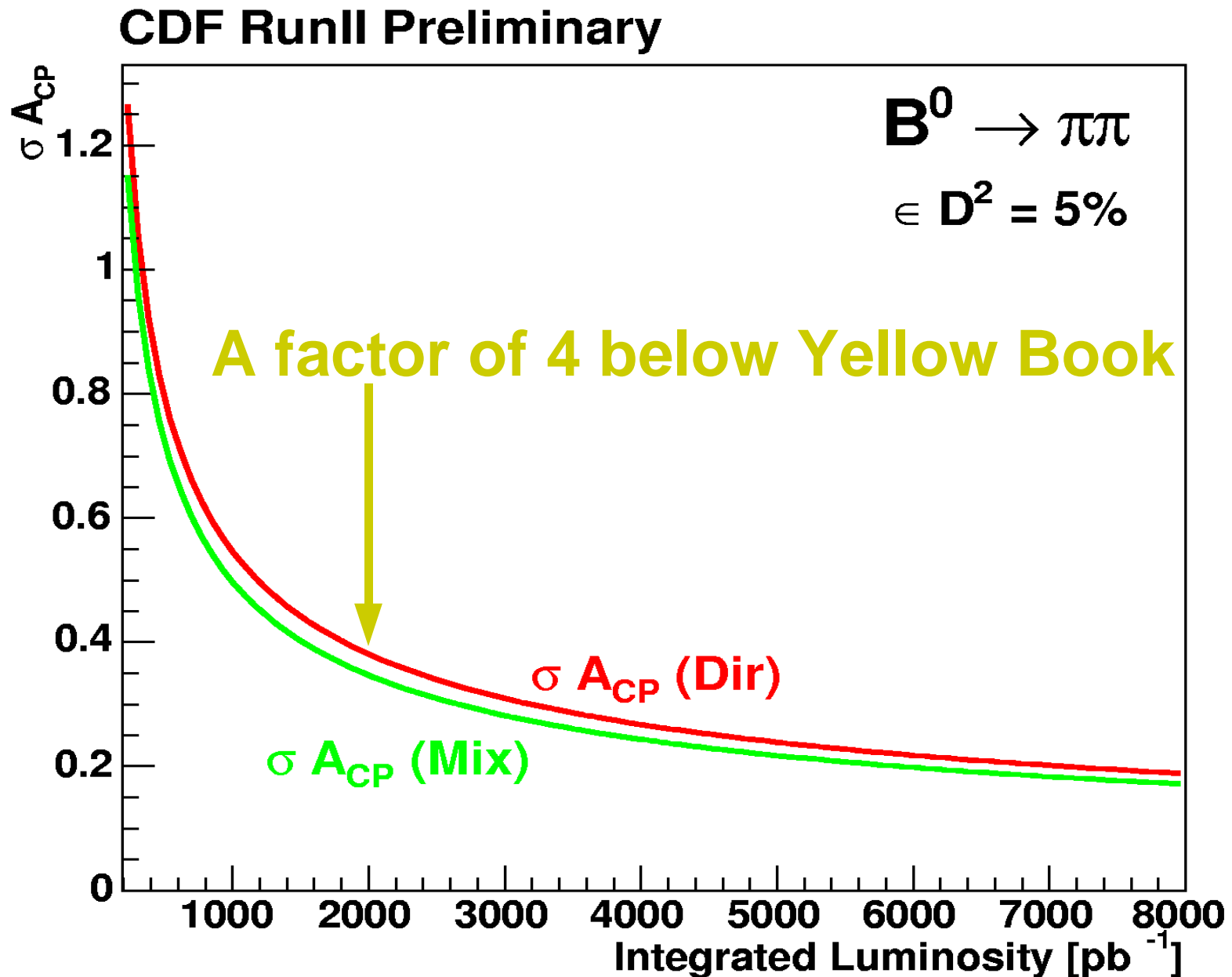
Small

$\Rightarrow$  Trigger favors mixing  $A_{CP}$  (due to Lxy cut)

$$A_{CP}(B_s) = A_{CP}^{\text{dir}} \cos \Delta m_s t + A_{CP}^{\text{mix}} \sin \Delta m_s t$$

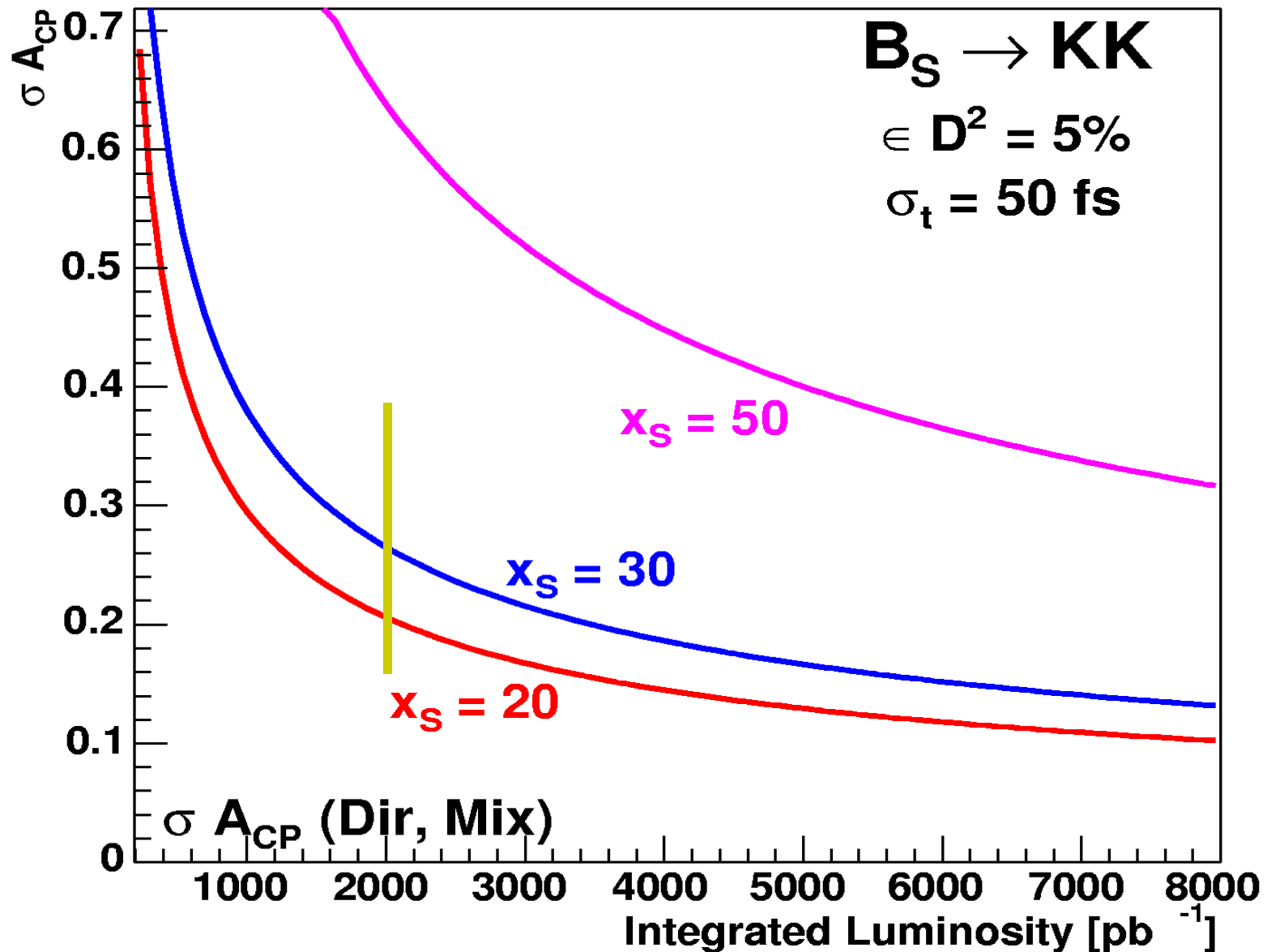
Large but unknown

# Error on $A_{CP}$ vs luminosity



# Error on $A_{CP}$ vs luminosity

CDF RunII Preliminary

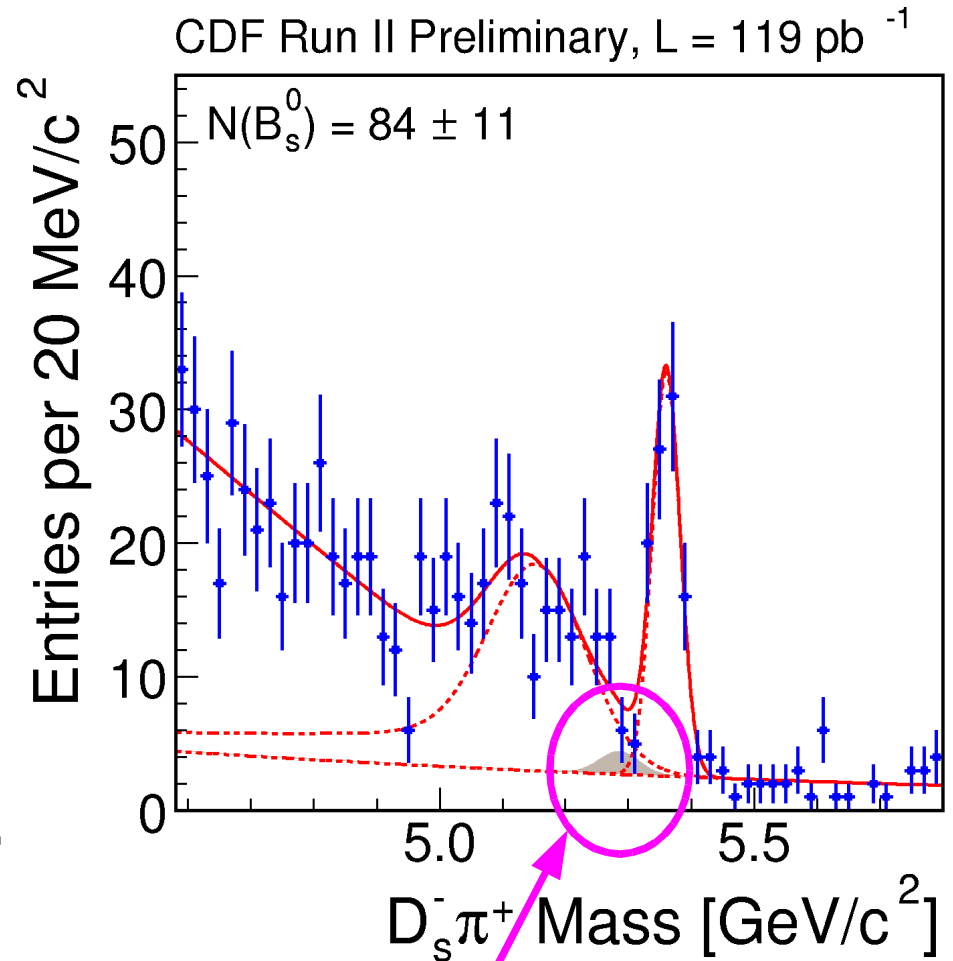
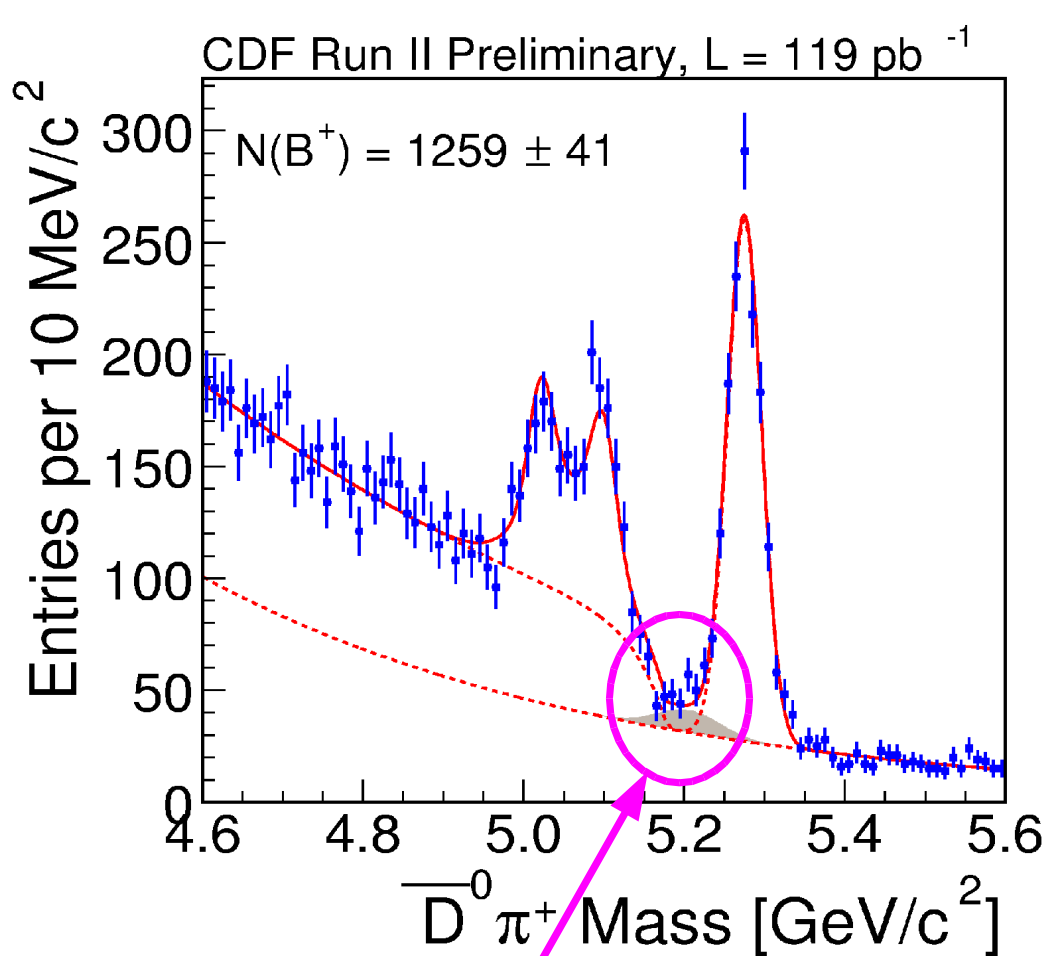


# $B \rightarrow DK$ Decay modes

- Estimates of yields only
- Need to do a combined mass vs dE/dx fit for Cabibbo suppressed  $B \rightarrow DK$  modes first
- $B_s \rightarrow D_s K$  tied to  $B_s$  mixing in  $B_s \rightarrow D_s \pi$
- BaBar/Belle:  $\frac{BR(B^+ \rightarrow D^0 K)}{BR(B^+ \rightarrow D^0 \pi)} = (8.31 \pm 0.35 \pm 0.20)\%$

Mode	Yield in $2 \text{ fb}^{-1}$	Yield in $3.5 \text{ fb}^{-1}$
$B^\pm \rightarrow \bar{D}^0 \pi, \bar{D}^0 \rightarrow K \pi$	48,000	84,000
$B^\pm \rightarrow \bar{D}^0 K, \bar{D}^0 \rightarrow K \pi$	3990	6980
$B^\pm \rightarrow \bar{D}^0 K, (\bar{D}^0 \rightarrow KK + \bar{D}^0 \rightarrow \pi\pi)$	520	910
$B_s \rightarrow D_s \pi, D_s \rightarrow \phi \pi$	3200	5600
$B_s \rightarrow D_s K, D_s \rightarrow \phi \pi$	256	448

# $B \rightarrow DK$ mass plots



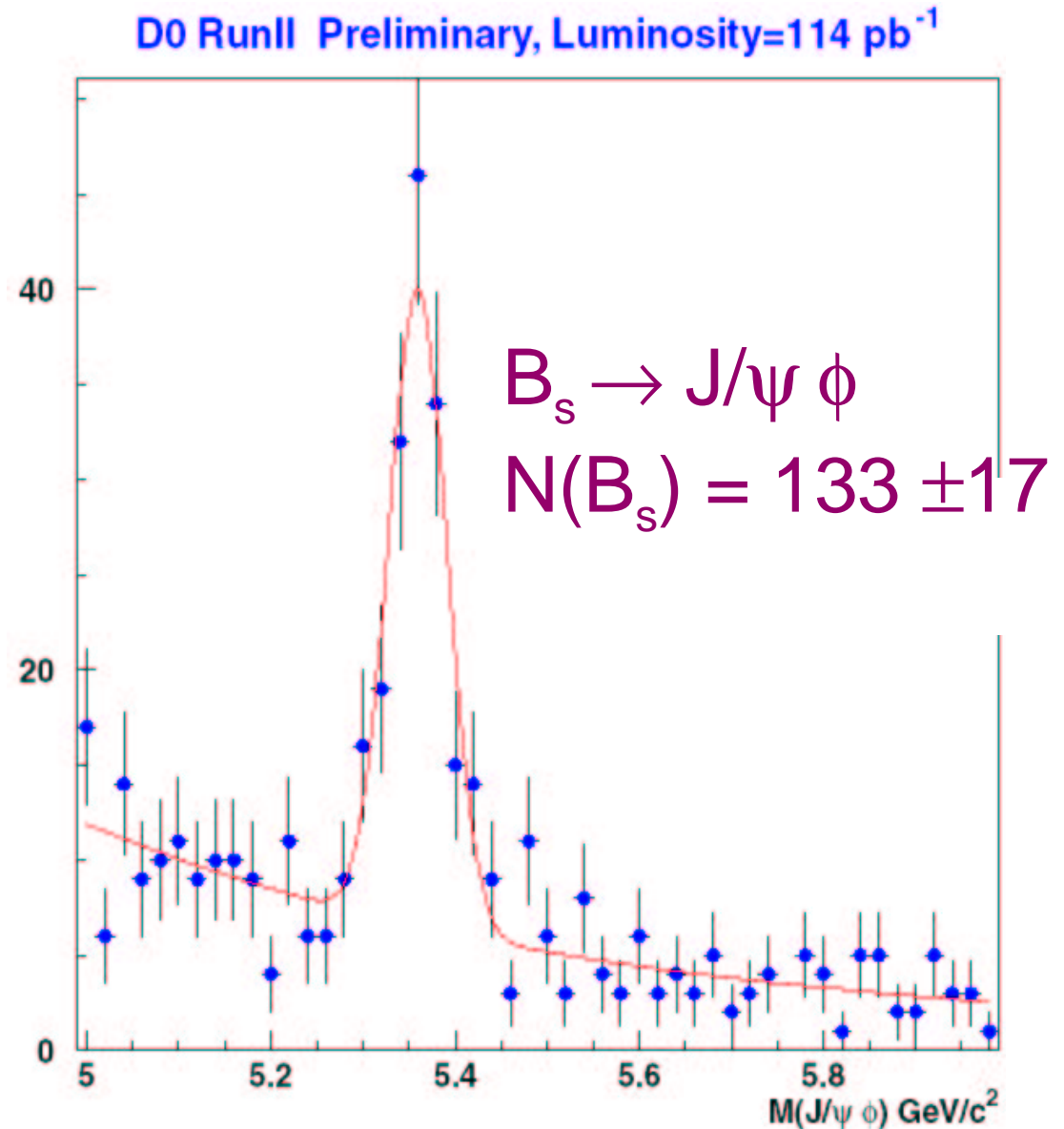
# CP violation in $B_s \rightarrow J/\psi \phi$

- Both D0 and CDF
- Needs  $\mathcal{X}_s$  first
- Measures

$$\beta_s \equiv \arg \left( -\frac{V_{ts} V_{tb}^*}{V_{cs} V_{cb}^*} \right)$$

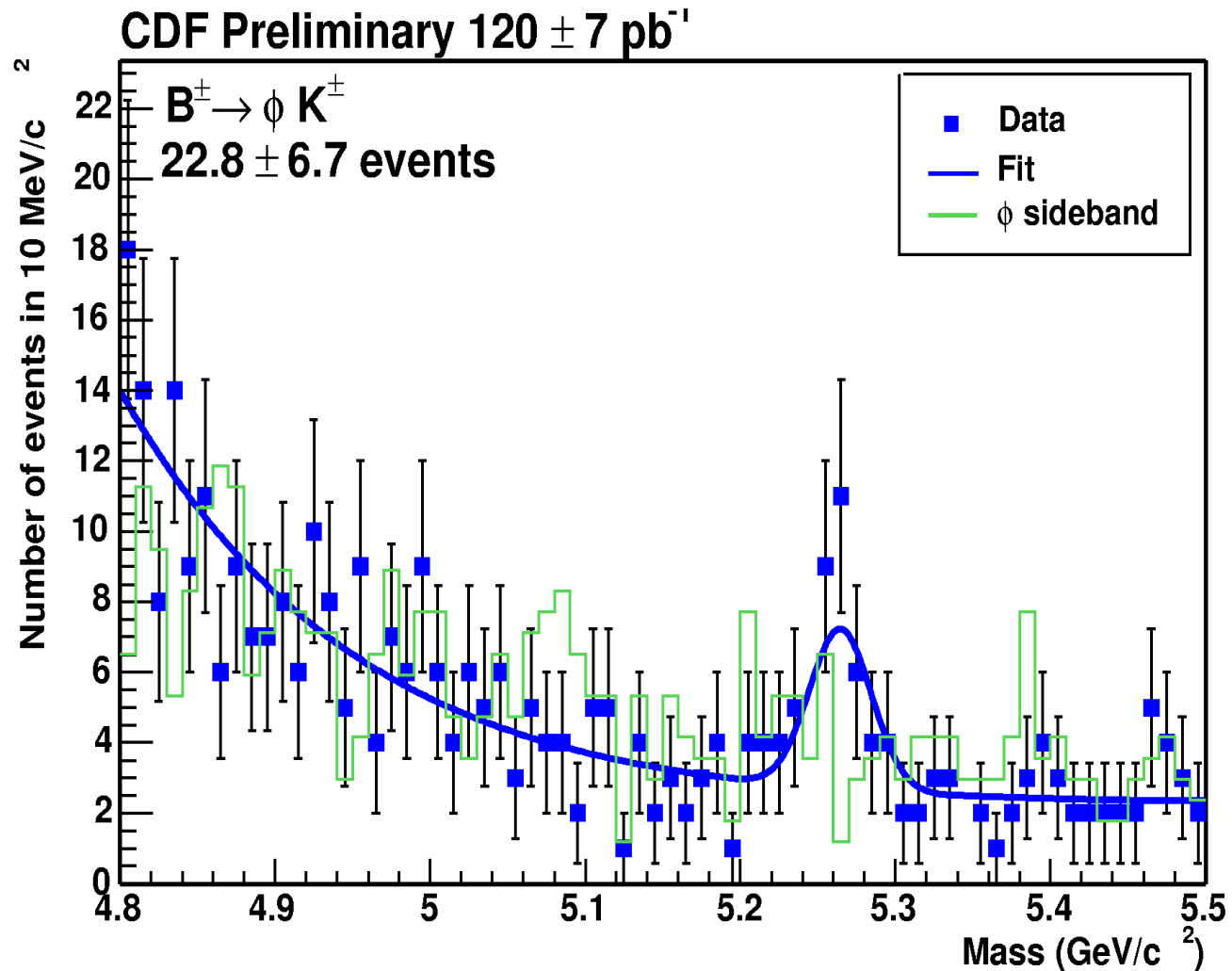
(directly  $\sim \eta$ )

- CDF's yield:  
 $120 \pm 13$  events  
in 140 pb<sup>-1</sup>



# Direct CP violation

- $B^+ \rightarrow \phi K^+$   
etc. especially  
interesting
- $B^0 \rightarrow \phi K_s^0$ : a  
dedicated phi  
trigger will help
- Measure  $A_{CP}$   
for all decay  
modes



- Baryons too! e.g.  $\Lambda_b \rightarrow pK$ , and  $\Lambda_b \rightarrow p\pi$

Food for thought: what if  $A_{CP} \neq 0$ ?

# Direct CP violation in Charm

- $D^{*+} \rightarrow D_{CP}^0 \pi^+$  (comparison from a recent review):

Table 7: Comparison of measurements in  $A_{CP}$  for  $D^0$  modes, from E791 (89), FOCUS (90), CDF (88), and CLEO (78)

	Mode	$A_{CP}$	Mode	$A_{CP}$
CLEO	$D^0 \rightarrow K^+ K^-$	$(0.0 \pm 2.2 \pm 0.8)\%$	$D^0 \rightarrow \pi^+ \pi^-$	$(1.9 \pm 3.2 \pm 0.8)\%$
E791	$D^0 \rightarrow K^+ K^-$	$(-1.0 \pm 4.9 \pm 1.2)\%$	$D^0 \rightarrow \pi^+ \pi^-$	$(-4.9 \pm 7.8 \pm 2.5)\%$
FOCUS	$D^0 \rightarrow K^+ K^-$	$(-0.1 \pm 2.2 \pm 1.5)\%$	$D^0 \rightarrow \pi^+ \pi^-$	$(4.8 \pm 3.9 \pm 2.5)\%$
CDF	$D^0 \rightarrow K^+ K^-$	$(2.0 \pm 1.7 \pm 0.6)\%$	$D^0 \rightarrow \pi^+ \pi^-$	$(3.0 \pm 1.9 \pm 0.6)\%$
CLEO	$D^0 \rightarrow K_S^0 \pi^0$	$(0.1 \pm 1.3)\%$	$D^0 \rightarrow \pi^0 \pi^0$	$(0.1 \pm 4.8)\%$
CLEO	$D^0 \rightarrow K_S K_S^0$	$(-23 \pm 19)\%$		

- Projections for 2 fb<sup>-1</sup>:

$$\begin{array}{llll}
 D^0 \rightarrow \pi^+ \pi^- & 0.4\% & 1.9\% \cdot \sqrt{65/2000} \\
 D^0 \rightarrow K^+ K^- & 0.3\% & 1.7\% \cdot \sqrt{65/2000} \\
 D^+ \rightarrow \pi^+ \pi^- \pi^+ & 0.2\% & 1/\sqrt{5\text{nb} \cdot 2\text{fb}^{-1}/30}
 \end{array}$$

# Summary

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- CDF and D0 **ready for CP violation studies:**
  - excellent understanding of tracking and of
  - most low-level components (e.g.  $dE/dx$ )
  - **New:** *use of L00* in CDF and *D0 trigger hardware*
- Bottom line: **below Yellow Book estimates**
  - Improvements possible, require work
- Focus on **Bs, baryons** and **low rate modes**
- Exploit searches for **direct CP violation**
- Hidden opportunities in **charm sector!**

# Backup slides

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# $\sin 2\beta$

- D0 yield will improve due to new trigger hardware (just coming online)
- No updates on  $\sigma(\sin 2\beta)$  yet

D0 RunII Preliminary, Luminosity =  $114 \text{ pb}^{-1}$

